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## Experimental Study on Comparing Intensities of Burnishing and Machine Hammer Peening Processes

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### Abstract

Many components in industrial practice need to be finished by surface modification processes in order to assure service properties like fatigue resistance, tribological properties and corrosion resistance. In order to compare the potential of different machine hammer peening (MHP) processes and burnishing Almen strips were treated with three aims: highest deflection, lowest surface roughness and predefined similar process parameters. This paper presents results of the surface layer states, in particular residual stresses, micro hardness and surface roughness in comparison to the deflection of the Almen strips after processing with the above mentioned aims.

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Keywords: Surface Integrity; Processing; Surface Modification Process

### 1. Introduction

Surface modification processes are important to improve the surface layer and adapt the workpiece properties to desired functions. Next to the conventional processes shot peening and burnishing, alternative processes have been developed in the last years, like machine hammer peening (MHP). Common for all MHP processes is a linear moving and vertically oscillating hammer head, which provides kinetic energy for an impact onto the workpiece surface [1]. Additionally, special cases of a stroke-controlled process are included to MHP processes. The intention of the process can be smoothing, surface texturing, induction of strain hardening or compressive residual stresses or a combination of two or more of these.

Since all MHP processes have common characteristics, some significant differences prevail, so this study intends to compare MHP and burnishing processes in order to investigate their effects on surface integrity. The chosen MHP processes are electromagnetic MHP (E-MHP) [2], pneumatic MHP (P-MHP) [3], Ultrasonic Nanocrystalline Surface Modification

(UNSM) [4] and Piezopeening [5]. The comparison is achieved by a treatment of standardized Almen strips and measurement of the deflection, residual stress state, micro hardness and surface roughness.

### 2. Experimental Setup

A method for testing the effectiveness of surface modifications was introduced by John O. Almen in 1944 [6]. The method determines a defined intensity value. Standardized Almen strips made of SAE 1070 were distributed to different universities and companies and processed by experts in their field using the following technologies: Ultrasonic Nanocrystalline Surface Modification (UNSM), hydraulic burnishing (RWTH Aachen: index 1; University of Alabama: index 2), Piezopeening, pneumatic machine hammer peening (P-MHP), electromagnetic machine hammer peening (E-MHP) as well as diamond smoothing. Additionally the comparison includes the deterministic surface modification processes burnishing and smoothing using the burnishing tool HG 6/13

of the Ecoroll AG, Germany. The Almen strip (type: A and C, grade: 1S, A: thickness: 1.27-1.32 mm, initial surface residual stress -250 MPa, C: thickness: 2.36-2.41 mm, initial surface residual stress -500 MPa) as well as the processing path are shown in Fig. 1. In order to avoid the influence of different machine kinematics, the strips were processed beyond the edge, except for burnishing 1 and UNSM, where a 2 mm distance to the edge was kept. In case of UNSM, the treatment beyond the edge was not technically feasible.

During the tests three parameter sets were performed each: The first configuration is defined as the process with a maximum of deflection of the Almen strip. The second is specified as the process yielding a minimum of surface roughness whereas the third configuration was set to common parameters for the different treatment processes, see Table 1 for details. The tool diameter is between 4 to 6 mm. There no common diameter for all processes was available. A feed rate

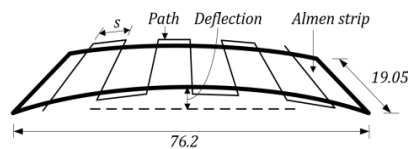


Fig. 1: Schematic figure of the treatment and deflection of the Almen strip

Table 1: Overview of the process parameters, legend: d = diameter, v = feed rate, s = stepover distance, h = stroke

Target	Parameters			Process specific parameters		
	d [mm]	v [m/min]	s [mm]			
<b>Burnishing 1: RWTH Aachen, Germany</b>						
	d	v	s	Contact force [N]		
Max. deflect.	13	3	0.1	1920 N		
Min. rough.	13	3	0.1	960 N		
Com. param.	6	3	0.3	530 N		
<b>Burnishing 2: University of Alabama, USA</b>						
	d	v	s	Contact force [N]		
Max. deflect.	6	3	0.1	373 N		
Min. rough.	6	3	0.1	64 N		
Com. param.	6	3	0.3	373 N		
<b>P-MHP: Techn. University Darmstadt, Daimler Sindelfingen, Germany</b>						
	d	v	s	Frequency [Hz]	Pneumatic pressure	
Max. deflect.	4	1	0.1	230-250	7 bar	
Min. rough.	20	1	0.1	230-250	7 bar	
Com. param.	4	3	0.3	230-250	7 bar	
<b>Piezopeening: Karlsruhe Institute of Technology, Germany</b>						
	d	v	s	Frequency [Hz]	h [mm]	Tool hardness
Max. deflect.	5	1	0.3	500	0.018	1500
Min. rough.	10	3	0.1	500	0.018	755
Com. param.	5	3	0.3	500	0.018	1500
<b>E-MHP: Vienna University of Technology, Austria</b>						
	d	v	s	Frequency [Hz]	h [mm]	
Max. deflect.	3	1.2	0.1	200	0.8	
Min. rough.	12	1.2	0.1	200	0.1	
Com. param.	5	3	0.3	200	0.5	
<b>UNSM: Sun Moon University, Korea</b>						
	d	v	s	Frequency [Hz]	h [mm]	Load [N]
Max. deflect.	2.38	2	0.07	20000	0.3	80
Min. rough.	6	2	0.07	20000	0.1	40
Com. param.	6	3	0.3	20000	0.3	60
<b>Smoothing: Baublies AG, Germany</b>						
	d	v	s	Axial load [N]		
Max. deflect.	13	3	0.1	1500		
Min. rough.	13	3	0.1	1000		
Com. param.	6	3	0.3	550		

of 3 m/min and a stepover distance of 0.3 mm were chosen in order to get a representing comparison of the capabilities of the different technologies and to achieve industry relevant process times. Further process specific parameters have not been predefined in this evaluation.

The surface layer state of the machined specimens was tested with respect to deflection, surface-roughness, micro-hardness as well as residual stresses. The deflection was measured using an Almen Gauge. The industry relevant surface roughness value  $R_z$  according to EN ISO 25178 was obtained using a 3D surface metrology device based on the focus variation principle. The micro hardness depth profiles were determined by 20 indentations down to a depth of 40  $\mu\text{m}$  using a Fisherscope HM2000. To minimize effects between the indentations, the measurements were taken along a diagonal. Indentation force was 10 mN, which corresponds to a Vicker's hardness of HV0.001. Residual stresses in the middle of the peening area were measured by using X-ray residual stress analysis according to the  $\sin^2\psi$ -method [7]. Residual stress depth distribution was analyzed by incremental electrolytic layer removal. Stress redistributions due to layer removal were not taken into account.

### 3. Results

#### 3.1. Hardness measurements

Most of the surface hardness values of the processed specimens lie within one standard deviation range (50 HV0.001) corresponding to the mean initial hardness of the unprocessed Almen strips with the mean value of 528 HV0.001 (see Fig. 2). Concerning hardness depth profiles, no hardness gradient along the offset from the specimen surface can be observed. Furthermore, there are no clear differences between hardness depth profiles after Piezopeening, P-MHP and UNSM specimens for all tested parameter combinations. In burnishing similar results with common process parameters and parameters for minimal roughness were achieved. Two burnished specimens, both processed with parameters to achieve maximum compressive residual stresses, demonstrate on average lower hardness of the surface layer. The same applies to the E-MHP and the smoothing treated specimen, as they have similar scattering and a lower average value. The full width at half maximum (FWHM) determined from X-ray measurements is a measure of the strain hardening as well. In contrast to the microhardness, an increase of FWHM at surface can be seen for some parameter sets, especially in case of maximum deflection after UNSM.

#### 3.2. Comparison of maximum deflection

Residual stress and surface roughness as a result of the treatment are shown in Fig. 3 and Fig. 4.

The process which comes along with both the highest deflection and the highest residual compressive stresses is UNSM. Burnishing experiments in Aachen produced low tensile residual stresses at moderate deflection values. Lowest deflection values were reached by burnishing experiments performed at the University of Alabama.

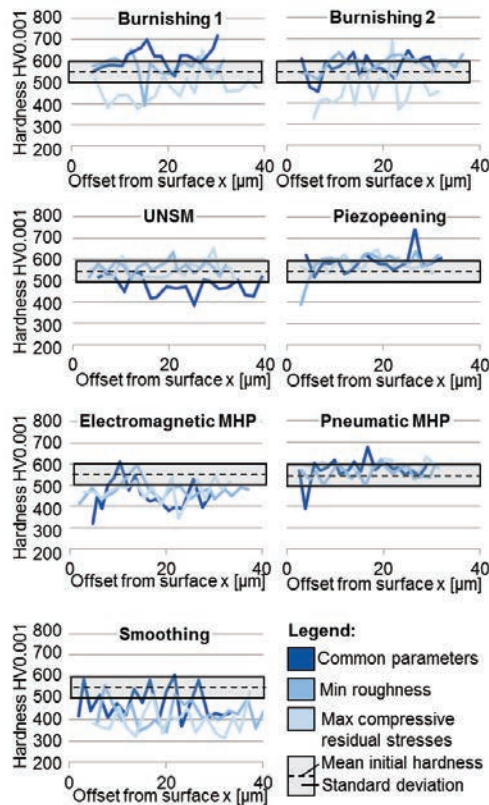


Fig. 2: Hardness depths distributions after burnishing and MHP-treatment

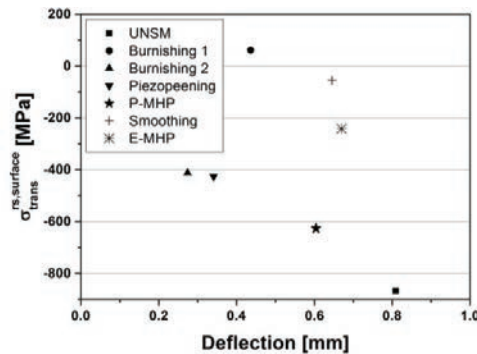


Fig. 3: Comparison of surface modification processes at maximum deflection using the correlation of transversal surface residual stresses with deflection

The evaluation of surface roughness of the specimens revealed that diamond smoothing produced the lowest values, while attaining the third largest deflection. Burnishing in Aachen also achieved a smoother surface than the initial state, whereas all specimens except for UNSM were in a comparable range. A correlation between high compressive residual stresses and high surface roughness can be assumed. Low stepover distance  $s$  values results in high compressive residual stresses, however in combination with small ball diameters the surface roughness can be increased.

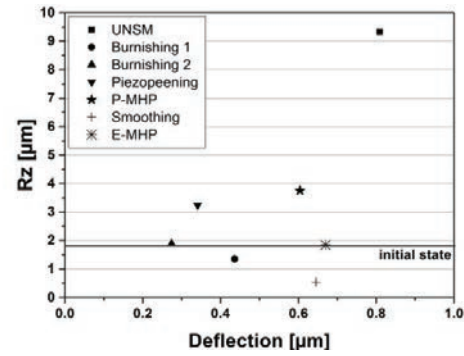


Fig. 4: Comparison of surface modification processes at maximum deflection using the correlation of roughness with deflection

### 3.3. Minimization of surface roughness

To obtain a minimum surface roughness, the processes were operated at medium/low loads while large tool diameters  $d$  were applied. Low stepover distances  $s$  values were chosen as well in order to ensure high overlapping of the processing paths [8]. All processes achieved similar, lower surface roughness values than the initial state of the Almen strips, whereas the E-MHP treatment provided the smoothest resulting surface quality (see Fig. 5). It has to be taken into account that in the case of smoothing with the maximum deflection parameters and UNSM with the common parameter set a lower roughness than  $R_z = 0.5 \mu\text{m}$  was achieved. A wide range of residual stress values were generated. UNSM produced the highest compressive residual stresses, while burnishing 1 and smoothing resulted in moderate tensile residual stresses (see Fig. 6).

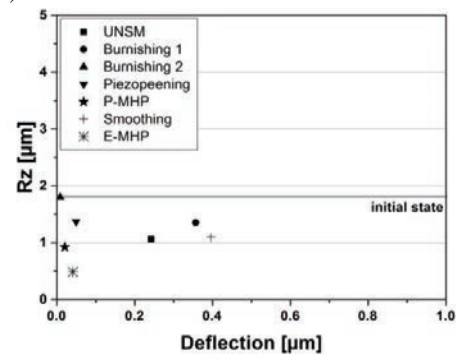


Fig. 5: Comparison of surface modification processes at minimum surface roughness using the correlation of roughness with deflection

### 3.4. Comparison common parameters

It could be shown that E-MHP and P-MHP achieved the lowest residual stresses, while Piezopeening and UNSM realized the highest compressive residual stresses (see Fig. 7).

When looking at the surface roughness in Fig. 8 the evaluation shows that a smoothing comparable to the initial surface is only achieved by UNSM and E-MHP. P-MHP achieved the highest  $R_z$  values. The overall perspective of the

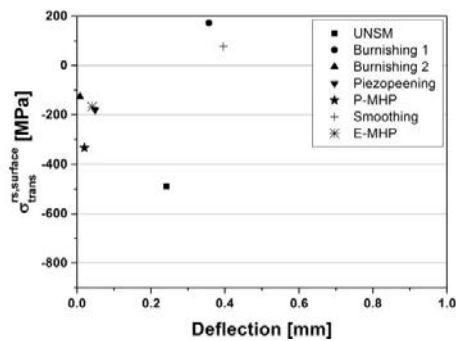


Fig. 6: Comparison of surface modification processes at minimum surface roughness using the correlation of transversal surface residual stresses with deflection

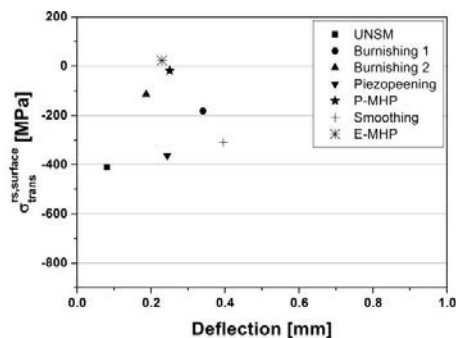


Fig. 7: Comparison of surface modification processes at common parameter using the correlation of transversal surface residual stresses with deflection

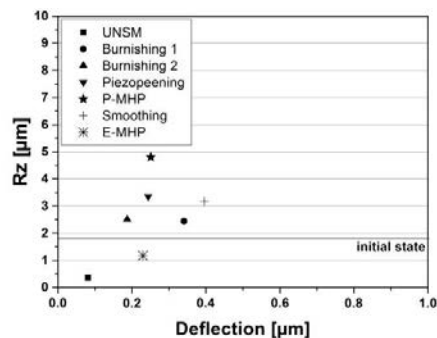


Fig. 8: Comparison of surface modification processes at common parameter using the correlation of roughness with deflection

results reveals that the resulting values for all processes were in the same order of magnitude. The differences in the various MHP-variants may be traced back to differences in slip behavior and the different rates of impact or stroke applicable to the individual processes. The change in diameter does not have a significant influence as is observed in Fig. 7 and 8.

#### 4. Conclusion

Generally, all processes show the potential to induce specific surface layer states using suitable process parameters. The resulting surface roughness and maximum residual stresses for all parameter sets are depicted in Fig. 9. The roughness is

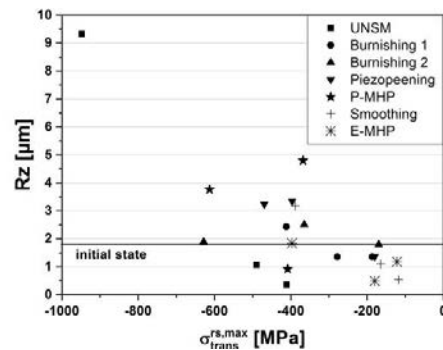


Fig. 9: Comparison of surface modification processes for all parameter sets using the correlation of roughness with maximum residual stresses

reduced down to 25 % of the initial value and compressive residual stresses are induced for all processes. The UNSM process shows the largest range from very smooth surface with medium residual stresses to very high surface roughness and high compressive residual stresses. The main difference to the other MHP process is the frequency. UNSM is processed with 20 kHz in contrast to 200-500 Hz for the other MHP processes. This results in a much higher coverage of the surface and higher strain rates. A higher coverage leads to lower surface roughness [8], which is an advantage of the UNSM process, however E-MHP and diamond smoothing showed comparable surface qualities. The high strain rate of UNSM may be a reason for the highest compressive residual stresses. The hardness measurements not revealed significant change in hardness, which is likely due to the high initial hardness of the Almen strip material. The treatment beyond the edges of the Almen strips was chosen to have a constant coverage at the edges. A higher coverage at the edges due to deceleration of the machine is supposed to lead to higher deflection, which could not be confirmed by a comparison of the results of burnishing 1 and 2.

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